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VACUUM PUMP

The invention relates to a vacuum pump.

Vacuum processing is commonly used in the manufacture of semiconductor devices to deposit thin films on to substrates. Typically, a processing chamber is evacuated using a vacuum pump to a very low pressure, which, depending on the type of process, may be as low as 10^{-6}mbar, and feed gases are introduced to the evacuated chamber to cause the desired material to be deposited on one or more substrates located in the chamber. Upon completion of the deposition, the substrate is removed from the chamber and another substrate is inserted for repetition of the deposition process.

Significant vacuum pumping time is required to evacuate the processing chamber to the required pressure. Therefore, in order to maintain the pressure in the chamber at or around the required level when changing substrates, transfer chambers and load lock chambers are typically used. The capacity of the load lock chamber can range from just a few litres to several thousand litres for some of the larger flat panel display tools.

The load lock chamber typically has a first window, which can be selectively opened to allow substrates to be transferred between the load lock chamber and the transfer chamber, and a second window, which can be selectively opened to the atmosphere to allow substrates to be inserted into and removed from the load lock chamber. In use, the processing chamber is maintained at the desired vacuum by the processing chamber vacuum pump. With the first window closed, the second window is opened to the atmosphere to allow the substrate to be inserted into the load lock chamber. The second window is then closed, and, using a load lock vacuum pump, the load lock chamber is evacuated until the load lock chamber is at substantially the same pressure as the transfer chamber, typically around 0.1mbar. The first window is then opened to allow the substrate to be transferred to the transfer chamber. The transfer chamber is then

evacuated to a pressure at substantially the same pressure as the processing chamber, whereupon the substrate is transferred to the processing chamber.

When vacuum processing has been completed, the processed substrate is transferred back to the load lock chamber. With the first window closed to maintain the vacuum in the transfer chamber, the pressure in the load lock chamber is brought up to atmospheric pressure by allowing a non-reactive gas, such as air or nitrogen, to flow into the load lock chamber. When the pressure in the load lock chamber is at or near atmospheric pressure, the second window is opened to allow the processed substrate to be removed. Thus, for a load lock chamber, a repeating cycle of evacuation from atmosphere to a medium vacuum (around 0.1mbar) is required.

Load lock pumps are typically oil-free in their vacuum chambers, as any lubricants present in the vacuum chambers might cause contamination of the clean environment in which the vacuum processing is performed. For example, the "iH" series of BOC Edwards "dry" vacuum pumps comprise a dry backing, or roughing, pump in combination with a single stage Roots mechanism booster, or blower, pump mounted above the dry pump. Backing pumps are commonly multi-stage positive displacement pumps employing inter-meshing rotors. The rotors may have the same type of profile in each stage or the profile may change from stage to stage.

For the larger flat panel display tools, the pumping speed of the load lock pumps needs to be high, for example, up to 2000m^3/hour. Whilst a load lock pump formed from a dry backing pump using Roots and Northey mechanisms, in series with a Roots booster pump can provide such a pumping speed, the relatively large foot-print of the pump combination, together with the level of noise and vibration generated during use, typically lead to the load lock pump being located remote from the processing tool, for example, in a basement. As well as being inconvenient to the user, relatively long runs of large diameter pipe work are

needed to connect the load lock pump to the load lock chamber, significantly increasing installation costs.

It is an aim of at least the preferred embodiments of the present invention to solve these and other problems.

In summary, in accordance with the present invention at least one of the booster pump and the backing pump in the conventional pumping arrangement is replaced by a vacuum pump comprising a multi-stage centrifugal compressor system. In one embodiment, both the booster pump and the backing pump are replaced by a single vacuum pump exhausting to atmosphere. In a second embodiment, the booster pump is provided by a similar vacuum pump to the first embodiment, having a reduced number of compressor stages, backed by a backing pump. This backing pump may be a conventional backing pump, or, in accordance with a third embodiment, may be a vacuum pump comprising a multi-stage centrifugal compressor system exhausting to atmosphere. Such a backing pump may be provided with a conventional Roots booster pump. Thus, in one aspect, the present invention provides a vacuum pump comprising a multi-stage centrifugal compressor mechanism for receiving fluid to be pumped and exhausting pumped fluid substantially at atmospheric pressure.

Due to the reduced levels of size, noise and vibration associated with a centrifugal compressor system in comparison to the conventional dry pumps, replacing one or both of the conventional backing and booster pumps with a pump comprising a multi-stage centrifugal compressor mechanism can enable at least part of the pumping arrangement to be mounted on the processing tool, thereby potentially avoiding the expensive long runs of large diameter pipe work.

It is desirable to perform the evacuation of a vacuum chamber, such as a load lock chamber, from atmospheric pressure to a low pressure as quickly as possible. The faster that this evacuation can be accomplished, the higher the rate of processing substrates becomes. However, during the initial stages of the

evacuation of a chamber from atmospheric pressure using a pump having a multi-stage pumping mechanism, the compression of fluid by the pumping mechanism can cause the fluid pressure to increase above atmospheric pressure. This can result in undesirable overloading of the exhaust stages of the pumping mechanism. If such a pump is operated for a significant period in this condition, damage can occur in the form of seals and/or bearings failing, or by impact between the fragile rotating impellers and pump's housing.

In view of this, in another aspect the present invention provides a multi-stage centrifugal compressor mechanism comprising a housing, a drive shaft rotatably mounted within the housing, a plurality of fixed members disposed within the housing and defining a plurality of interconnected fluid chambers, a plurality of impellers mounted on the drive shaft and disposed relative to the fixed members such that each impeller delivers compressed fluid to a respective fluid chamber, a bypass channel extending between two of the fluid chambers to enable fluid to pass between those chambers without compression, and means for controlling the flow of fluid through the bypass channel. Compressed fluid can thus be conveyed between fluid chambers without compression, which can enable a larger upstream pumping stage to operate at full speed without causing the pumped fluid to be pressurised above atmospheric pressure.

The control means is thus preferably arranged to open the bypass channel under the influence of a pressure difference between said two of the fluid chambers, and in particular when the pressure in an upstream one of said two of the fluid chambers is greater than the pressure in a downstream one of said two of the fluid chambers.

In a preferred embodiment, said two of the fluid chambers are adjacent fluid chambers of the compressor mechanism, although one or more other fluid chambers may, alternatively, separate these two fluid chambers. For example, one of the fluid chambers may be the first, lowest pressure fluid chamber of the pumping mechanism, and the other fluid chamber by the last, highest pressure

fluid chamber of the pumping mechanism. Where these two fluid chambers are adjacent, however, the bypass channel may conveniently pass through the fixed member located between the fluid chambers.

The control means preferably comprises valve means, for example, a valve member displaceable in use between a closed position and an open position by pressurised fluid. Such a valve member may be conveniently provided by a flap valve, which can be conveniently positioned within a fluid chamber to control the flow of fluid into that fluid chamber from the bypass channel.

Preferably, the mechanism comprises, for each fluid chamber, a respective bypass channel extending between that fluid chamber and the adjacent downstream fluid chamber, and means for controlling the flow of fluid through each bypass channel.

Centrifugal compressor mechanisms are susceptible to surging of pumped fluid when the specific flow rate of the pumped fluid through a stage of the compressor mechanism is relatively low. The surging manifests itself in a backflow of fluid into the compressor impeller, and adversely affects the efficient operation of the vacuum pump, and in extreme conditions, may actually damage the pump. In view of this, the mechanism preferably comprises surge control means for controlling surge within the compressor mechanism. Therefore, in a further aspect the present invention provides a multi-stage centrifugal compressor mechanism comprising a housing, a drive shaft rotatably mounted within the housing, a plurality of fixed members disposed within the housing and defining a plurality of interconnected fluid chambers, a plurality of impellers mounted on the drive shaft and disposed relative to the fixed members such that each impeller delivers compressed fluid to a respective fluid chamber, and surge control means for controlling surge within the multi-stage centrifugal compressor mechanism.

The surge control means preferably comprises means for conveying a stream of fluid to each fluid chamber, and means for controlling the rate of flow of the fluid stream into each fluid chamber. In one embodiment, the conveying means is

arranged to convey a stream of gas, such as air, nitrogen or an inert gas, to each fluid chamber. In another embodiment, the conveying means is arranged to convey a stream of compressed fluid to each fluid chamber. In either case, the rate of flow through the compressor mechanism can be maintained at a value above that at which surging will occur.

Where the conveying means is arranged to convey a stream of compressed fluid to each fluid chamber from a downstream fluid chamber, the conveying means preferably comprises, for each fluid chamber, a fluid passage (separate from the previously-mentioned bypass channel) extending between that fluid chamber and the adjacent downstream fluid chamber. These fluid passages are preferably co-axial.

The means for controlling the rate of flow of the fluid stream into each fluid chamber preferably comprises valve means. The valve means may comprise a series of valves for controlling fluid flow through respective fluid passages or a spool valve for controlling fluid flow through each fluid passage. The valve means is preferably located at least partially within the chamber, thereby avoiding the need to provide external pipe connections. The valve means may be controlled by a separate controller. In order to control the valve means, a pressure sensor may be provided to monitor the pressure of fluid passing through a pump inlet, a signal from the inlet sensor being supplied to a control system which controls the opening and closing of the valve means. In addition, or alternatively, pressure sensors may be provided within the pumping mechanism to monitor pressure fluctuation within the pumping mechanism, and thus detect the onset of surging.

Each impeller preferably has on one side thereof a plurality of vanes or blades extending between the inner periphery and the outer periphery thereof. Each blade preferably follows a curved path. To facilitate manufacture, each fixed member preferably comprises a disc integral with a respective part of the housing.

Fluid that is compressed by the compressor mechanism typically becomes hot. In order to cool fluid pumped by the compressor mechanism, particularly at the exhaust stages, the mechanism preferably comprises means for cooling each fixed member. For example, a plurality of cooling fins may be provided on one side thereof. Alternatively, or in addition, the cooling means may comprise means for supplying a flow of coolant to each fixed member. This can provide direct cooling of both the cooling fins (where provided) and the fixed plate. The cooling fins may be located between the fixed plate and a diffuser plate for directing a stream of compressed fluid from an impeller to a fluid chamber so that the fins can also provide for cooling of the diffuser plate.

The present invention also provides a vacuum pump comprising a compressor mechanism as aforementioned.

Excessive heating of the compressor mechanism may occur if the pump is operated over a relatively long period at a relatively high pressure, for example, if a door to a load lock chamber evacuated by the pump has been inadvertently left open. In order to prevent excessive heating of the pump, the temperature of the pump may be monitored, and the speed of rotation of the compressor mechanism varied in response to the monitored temperature. This can enable the speed of the pump to be reduced in the event of overheating, thereby reducing the temperature within the pump, and preventing the pump from being unduly operated at a high speed for a relatively long period.

Therefore, the pump preferably comprises means for monitoring the temperature of the pump, and means for controlling the speed of rotation of the shaft in dependence on the monitored temperature. The monitoring means may be conveniently provided by any suitable temperature sensor, such as a thermocouple, located within or in close proximity to the housing. A controller for controlling a motor driving the drive shaft may provide the control means.

In order to cool the housing, to which heat will be transferred by the pumped fluid, an external cooling system may also be provided, for example, in the form of a cooling jacket extending about at least part of the compressor mechanism.

Where the pump is to be used as a backing pump, the backing pump may consist of such a multi-stage centrifugal compressor mechanism, in combination with any suitable booster pump. Such a booster pump may be provided by a pump comprising such a multi-stage centrifugal compressor mechanism downstream from a molecular drag mechanism, the number of stages of the compressor mechanism (for example, two) being smaller in the booster pump than in the backing pump (for example, six or seven). Alternatively, the conventional combination of booster and backing pumps may be replaced by a single pump, this pump comprising a multi-stage (for example, six or seven stage) centrifugal compressor mechanism downstream from a multi-stage (for example, four stage) molecular drag mechanism. The molecular drag mechanism preferably comprises a multi-stage Holweck mechanism having a plurality of channels arranged as a plurality of helixes. The drag stages may be arranged in series, in parallel for maximum pumped volume, or in a combination of both. In order to minimise the length of the pump the molecular drag mechanism preferably at least partially surrounds a motor for rotating the drive shaft. For instance, where the molecular drag pumping mechanism is a Holweck mechanism, a rotor element of the molecular drag pumping mechanism typically comprises a cylinder mounted for rotary movement with the rotor elements of the compressor mechanism, which cylinder may at least partially surround the motor. This, in a further aspect the present invention provides a vacuum pump comprising a multi-stage centrifugal compressor mechanism comprising a plurality of rotor elements mounted on a rotatably mounted drive shaft, and, upstream therefrom, a molecular drag mechanism comprising at least one rotor element mounted on the drive shaft, wherein the at least one rotor element of the molecular drag mechanism at least partially surrounds a motor for rotating the drive shaft.

As discussed above, for rapid pump down of a chamber the pump may be provided with valve means for enabling compressed fluid to by-pass one or more of the impellers of the multi-stage centrifugal compressor mechanism, allowing the pump to pump down at full inlet speed even when the exhaust stages of the compressor mechanism are somewhat smaller than the inlet stages. With such a design, the backing pump may become a restriction to the flow of fluid through the pumping arrangement. Therefore, in a preferred arrangement a fluid by-pass conduit is connected between an exhaust from the booster pump and an exhaust from the backing pump, with means being provided for controlling the flow of fluid through the by-pass. Such an arrangement may be provided for any combination of booster and backing pumps.

Preferred features of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a cross-section through a first embodiment of a vacuum pump;

Figure 2 is a cross-section through a second embodiment of a vacuum pump, which is similar to that of Figure 1 with a different surge control mechanism;

Figure 3 is a cross-section through an embodiment of a booster pump, which is similar to that of Figure 1 with a reduced number of compressor stages;

Figure 4 is an enlarged view of part of the cross-section of Figure 3;

Figure 5 is a cross-section through an embodiment of a backing pump, which is similar to that of Figure 1 without a drag mechanism;

Figure 6 illustrates schematically an arrangement of valves in a pumping arrangement comprising a booster pump in series with a backing pump; and

Figure 7 illustrates schematically an arrangement for controlling the speed of a booster pump.

With reference to Figure 1, a vacuum pump 10 suitable for evacuating a load lock chamber comprises a housing 12 having three parts 14, 16, and 18. An inlet 20 for the pump 10 is located in the first part 14 of the housing 12, and an exhaust 21 for the pump 10 is located in the third part 18 of the housing 12.

The first part 14 of the housing 12 houses a multi-stage molecular drag pumping mechanism 22. As illustrated in Figure 1, in this embodiment the molecular drag pumping mechanism is provided by a four-stage Holweck mechanism 22, although any suitable number of pumping stages may be provided. The rotor of the Holweck mechanism 22 comprises two carbon-fibre cylinders 24, 26, mounted concentrically on a disc-like impeller 28 integral with or, as illustrated, mounted on a rotatable shaft 30. The shaft 30 is supported at each end by lubricant free bearings (not shown), preferably magnetic bearings, and is driven by a motor 31 housed by the third part 18 of the housing 12.

Each cylinder 24, 26 of the Holweck mechanism 22 has smooth inner and outer surfaces. The stator of the Holweck mechanism comprises a plurality of cylinders 32, 34 and 36 concentrically arranged with and surrounding the rotor cylinders 24, 26, the outermost cylinder 36 being provided by the first part 14 of the housing 12. Helical grooves are formed on the outer surfaces of the innermost stator cylinder 32, the inner and outer surfaces of the middle stator cylinder 34 and the inner surface of the outermost stator cylinder 36 to define co-axial helical fluid channels 38, 40, 42, 44, which receive fluid from the pump inlet 20 and exhaust pumped, compressed fluid to a common exhaust port 48 through openings 50 formed in the disc-like impeller 28.

The second part 16 of the housing 12 may be conveniently provided by a plurality of co-axial rings 16a, 16b, 16c, 16d, 16e, and 16f, and houses a multi-stage centrifugal compressor mechanism 52. In the embodiment shown in Figure 1, the

compressor mechanism 52 comprises seven pumping stages. Each of the first six pumping stages comprises a respective fluid chamber 58, each defined between respective discs 60 co-axially mounted on the inner wall of the second part 16 of the housing 12. Apertures 62 in the discs 60 interconnect the fluid chambers 58 to enable fluid to be conveyed from the exhaust port 48 of the Holweck mechanism 22 to the exhaust 21 of the pump through each of the fluid chambers 58 in turn.

Each fluid chamber 58 includes a rotor in the form of an impeller 54 mounted on the shaft 30. Each impeller 54 has a plurality of curved blades or vanes 56 located on the upper surface (as shown in Figure 1) of the impeller 54. The impellers 54 are disposed relative to the discs 60 such that, during use, each impeller 54 delivers compressed fluid to a respective fluid chamber 58.

Each fluid chamber 58 also includes a disc-like diffuser plate 64, each integral with a respective ring 16a, 16b, 16c, 16d, 16e, and 16f for directing compressed fluid output from the each of the impellers 54 radially outwardly. As a result, compressed fluid flows within the fluid chambers 58 in a serpentine manner; within each fluid chamber 58, compressed fluid initially flows radially outwards between the upper surface (as shown) of the diffuser plate 64 and the facing, lower surface of the upper disc 60 defining that fluid chamber, and subsequently flows radially inwards between the lower surface (as shown) of the diffuser plate 64 and the facing, upper surface of the lower disc defining that fluid chamber.

Each of the diffuser plates 64 comprises a plurality of cooling fins 66, provided on the lower surface thereof, for cooling the compressed fluid. In order to cool the housing 12, to which heat will be transferred by the fluid pumped by the compressor mechanism 52, an external pump cooling system (not shown) may also be provided, for example, in the form of a cooling jacket extending about at least the second part 16 of the housing 12.

In use, the motor is activated to rotate the shaft 30 at a high speed, typically in the range from 15,000 to 80,000 rpm. Fluid enters the pump 10 through the inlet 20, and passes in turn through the Holweck mechanism 22 and compressor mechanism 52 before being exhausted from the outlet of the pump 10 at a pressure at or around atmospheric pressure. With the arrangement shown in Figure 1, a pressure less than 1 mbar, typically at or around 0.1mbar, can be generated in a load lock chamber connected to the inlet 20 of the pump 10.

In order to inhibit surging within the compressor mechanism 52 at relatively low flow rates, the pump 10 is provided with a surge control mechanism for selectively increasing the rate of flow of fluid through one or more of the pumping stages of the compressor mechanism 52. In the first embodiment shown in Figure 1, a fluid port 68 is provided in each of the rings 16a, 16b, 16c, 16d, 16e, 16f, each port 68 extending radially through the ring to allow a stream of fluid to be injected into the fluid chamber 58. This stream of fluid may be provided by any suitable source. In a first example, the fluid ports 68 of adjacent pumping stages may be connected via an arrangement of conduits located to one side of the pump 10, the conduits containing one or more valves for selectively opening the conduits to allow pumped fluid from one pumping stage to flow from the fluid port 68 of that stage to the fluid port 68 of the adjacent upstream pumping stage, thereby increasing the rate of flow of fluid through the inlet to the pumping stage. In a second example, a stream of purge gas, such as nitrogen or air, may be selectively supplied from a suitable source to one of more of the fluid ports 68 in order to increase the rate of flow of fluid through one or more of the pumping stages.

In a third example, as illustrated in Figure 2, a passage 70 for compressed fluid may be provided through the pumping stages of the compressor mechanism 52 in addition to, or as an alternative to, providing fluid ports 68. The passage 70 is defined by a series of co-axial apertures 72 formed in the discs 60 co-axially mounted on the inner wall of the second part 16 of the housing 12. A spool valve 74 is provided for selectively opening and closing the apertures 72 to control the

flow of compressed fluid through the passage 70. As illustrated, the spool valve 74 may be shaped so that movement of the valve 74 causes all of the apertures 72 to be opened simultaneously to allow compressed fluid to flow through the apertures 72 to adjacent upstream pumping stages. Alternatively, the spool valve 74 may be shaped so that movement of the valve 74 causes each of the apertures 74 to be opened in turn, starting, for example, with the aperture 74 connecting the exhaust pumping stages of the compressor mechanism 52.

In order to control the valves in any of these three examples, a pressure sensor may be provided to monitor the pressure of fluid passing through the pump inlet 20. A signal from the inlet sensor may be supplied to a control system, which controls the opening and closing of the, or each, valve in order to inhibit surging. In addition, or alternatively, pressure sensors may be provided within the pump 10 to monitor pressure fluctuation within the pump, and thus detect the onset of surging. Motor current may also be used to indicate shaft torque and power, and thus an estimation of inlet pressure.

As the pumps illustrated in Figures 1 and 2 exhaust fluid at or around atmospheric pressure, each pump 10 would be suitable for replacing both the conventional booster and backing pump used for evacuating a load lock chamber. Due to the reduced size of the pump 10 relative to the size of the conventional combination of booster and backing pumps, and due to the reduced noise and vibration levels associated with the pump 10, the pump 10 may be conveniently mounted on the side of the processing tool.

By reducing the number of stages of the compressor mechanism 52, the pump 10 can be suitable for use as a booster pump. Figures 3 and 4 illustrate an embodiment of such a booster pump 100. The booster pump comprises a housing having three parts 102, 104, and 106. An inlet 110 for the pump 100 is located in the first part 102 of the housing, and an exhaust 112 for the pump 100 is located in the third part 106 of the housing.

The second part 104 of the housing houses a multi-stage molecular drag pumping mechanism 120. As illustrated in Figure 3, similar to the pump 10 of Figure 1 the molecular drag pumping mechanism is provided by a four-stage Holweck mechanism 120, although any suitable number of pumping stages may be provided. The rotor of the Holweck mechanism 120 comprises three carbon-fibre cylinders 122, 124, 126, mounted concentrically on a disc-like impeller 128 integral with or, as illustrated, mounted on a rotatable drive shaft 130. The shaft 130 is supported at each end by rolling bearings 132 and is driven by a motor 134 partially surrounded by the cylinders 122, 124, 126 of the Holweck mechanism 120.

Each cylinder of the Holweck mechanism 120 has smooth inner and outer surfaces. The stator of the Holweck mechanism 120 comprises a plurality of cylinders 136, 138 and 140 concentrically arranged with and surrounding the rotor cylinders 122, 124, 126, the outermost cylinder 36 being provided by, or, as illustrated, mounted on the second part 104 of the housing. Helical grooves are formed on the outer surface of the innermost stator cylinder 136, the inner and outer surfaces of the middle stator cylinder 138 and the inner surface of the outermost stator cylinder 140 to define co-axial helical fluid channels which receive fluid from the pump inlet 110 through one or more openings 142 formed in the disc-like impeller 128 and exhaust pumped, compressed fluid to a common exhaust port 144.

The second part 106 of the housing may be conveniently provided by a plurality of co-axial rings 106a, 106b, 106c, and 106d, and houses a multi-stage centrifugal compressor mechanism 150. In the embodiment shown in Figures 3 and 4, the compressor mechanism 150 comprises four pumping stages. Each of the first three pumping stages comprises a respective fluid chamber 158, each defined between respective discs 160 co-axially mounted on the inner wall of the second part 106. Apertures 162 in the discs 160 interconnect the fluid chambers 158 to enable fluid to be conveyed from the exhaust port 144 of the Holweck mechanism to the exhaust 112 of the pump through each of the fluid chambers 158 in turn.

Each fluid chamber 158 includes a rotor in the form of an impeller 154 mounted on the shaft 130. Each impeller 54 has a plurality of curved blades or vanes 156 located on the upper surface (as shown in Figure 1) of the impeller 154. The impellers 154 are disposed relative to the discs 160 such that, during use, each impeller 154 delivers compressed fluid to a respective fluid chamber 158.

Each fluid chamber 158 also includes a disc-like diffuser plate 164, each integral with a respective ring 106a, 106b, 106c, 106d, for directing compressed fluid output from the each of the impellers 154 radially outwardly. As a result, compressed fluid flows within the fluid chambers 158 in a serpentine manner; within each fluid chamber 158, compressed fluid initially flows radially outwards between the upper surface (as shown) of the diffuser plate 164 and the facing, lower surface of the upper disc 160 defining that fluid chamber, and subsequently flows radially inwards between the lower surface (as shown) of the diffuser plate 164 and the facing, upper surface of the lower disc 160 defining that fluid chamber.

Each of the diffuser plates 164 may comprise a plurality of cooling fins (not shown), provided on the lower surface thereof, for cooling the compressed fluid. In order to cool the fins, a coolant may be conveyed through cooling channels defined between the lower (as shown) surface of the diffuser plate 164 and the facing, upper surface of the lower disc 160.

In use, the motor is activated to rotate the shaft 130 at a high speed, typically in the range from 15,000 to 80,000 rpm. Fluid enters the pump 100 through the inlet 110, and passes in turn through the Holweck mechanism 120 and compressor mechanism 150 before being exhausted from the outlet 112 of the pump 100 at a sub-atmospheric pressure.

Similar to the pump described in Figure 1, a surge control mechanism may be provided to inhibit surging within the compressor mechanism. For example, as

shown in Figure 4, a fluid port 168 may provided in each of the rings 106a, 106b, and 106c, each port 168 extending radially through the ring to allow a stream of fluid to be injected into a respective fluid chamber 158. This stream of fluid may be provided by any suitable source. Preferably, such a mechanism would be operated only at relatively low inlet pressures in order to maximise throughput at relatively high inlet pressures.

In addition to such a surge control mechanism, an additional mechanism may also be provided to enable rapid pump down of a chamber attached to the inlet 110 of the booster pump 100 without overloading the exhaust stages of the compressor mechanism. As shown in Figure 4, one or more of the discs 160 are provided with bypass channels 170 for enabling compressed fluid to pass to an adjacent, downstream fluid chamber without compression by an impeller 154. The channels 170 are normally closed by a valve mechanism 172, which in this embodiment is in the form of a pair of flap valves having a common mounting within the downstream fluid chamber 158. The valve mechanism 172 is selectively opened by a pressure differential between fluid within the adjacent fluid chambers 158, so that when the pressure of fluid in the upstream fluid chamber is greater than that in the downstream fluid chamber, the valve opens to enable fluid to pass from the upstream fluid chamber to the downstream fluid chamber without compression.

This can enable gas being pumped by the pump 100 to pass through one or more of the smaller, exhaust stages of the compressor mechanism 150 without compression, thereby avoiding the gas from being compressed above atmospheric pressure by those exhaust stages and thus preventing those stages from becoming overloaded.

The booster pump 100 may be used in combination with any suitable backing pump. Figure 5 illustrates an embodiment of a backing pump 200 employing a multi-stage centrifugal compressor mechanism, which would be suitable for use with such a booster pump, or any conventional booster pump. The backing pump

200 is similar to the pump 10 illustrated in Figure 1, with the exception that the backing pump 200 does not require a drag mechanism as the fluid entering the backing pump 200 would be at a higher pressure than that entering the pump 10. In other words, the backing pump 200 comprises a multi-stage compressor mechanism 252 for receiving fluid from the pump inlet 220 and exhausting pumped fluid at or around atmospheric pressure from pump outlet 221. The compressor mechanism 252 of the backing pump 200 is similar to the compressor mechanism 52 of the pump 10, and so is not described in further detail here.

During pump down of a chamber attached to a series combination of the booster pump 100 and backing pump 200, depending on the pumping mechanism of the backing pump 200, the backing pump 200 may restrict the rapid evacuation of the chamber, as the backing pump 200 may not be able to pump the fluid exhaust from the booster pump 100 sufficiently quickly. In order to enable at least some of the gas pumped from the chamber to by-pass the backing pump 200, as shown in Figure 6 an external by-pass conduit 250 may be provided in fluid communication with the exhaust 112 of the booster pump 100 and the exhaust 221 of the backing pump 200. The by-pass conduit 250 preferably includes a by-pass valve 252 for opening the conduit 250 at high exhaust pressures from the booster pump 100 to enable "excess" fluid exhaust from booster pump 100 to by-pass the backing pump 200.

With reference now to Figure 7, in order to prevent overheating of, say, the booster pump 100 during pump down of a chamber attached to the inlet thereof, a the pump 100 may be provided with a temperature sensor 300 located, for example, within the housing of the pump 100, for outputting to a controller 302 a signal indicative of the current temperature within the housing of the pump 100. In response to the received signal, the controller 302 can issue a command to the motor 134 of the pump 100 to adjust the speed of rotation of the shaft 130. By reducing the speed of the pump, the temperature within the housing of the pump 100 can be reduced. As an alternative, or in addition, to the control of the speed of the pump in dependence on the temperature of the pump, the speed of the

pump may also be controlled in dependence on the pressure of gas being conveyed to the inlet 110 of the pump using a pressure sensor 304 located proximate the inlet of the pump.

In summary, two vacuum pumping arrangements are described for evacuating a load lock chamber. In the first arrangement, a single pump comprises a multi-stage molecular drag stage and a multi-stage centrifugal compressor mechanism exhausting pumped fluid at atmospheric pressure. In the second arrangement, a booster pump is provided in series with a backing pump. The booster pump is similar to the pump of the first arrangement, but with a reduced number of compressor mechanism stages. The backing pump also comprises a multi-stage centrifugal compressor mechanism exhausting pumped fluid at atmospheric pressure. Such arrangements can reduce noise, size and vibration levels associated with conventional load lock pumps.